THURSDAY, JULY 15, 1897.

THE ANCIENT VOLCANOES OF BRITAIN.

The Ancient Volcanoes of Britain. By Sir Archibald Geikie, F.R.S., Director-General of the Geological Survey. Vol. I., pp. xxiv. + 477; Vol. II., pp. xvi. + 492. (London: Macmillan and Co., Ltd., 1897.)

THE Edinburgh school of geology, when of old it formulated the theory of existing causes of terrestrial change, established the fundamental principle of modern geological science. Thanks to this school, men learnt how rocks were formed, how the strata of the earth's crust were built up, how slow had been the evolution of the continents and oceans, and how important is the conception of time in regard to the past history of the globe. The brilliant representative of this illustrious school who has recently published a history of the volcanoes of Great Britain, sets forth in this remarkable treatise the great features in the volcanic history of the earth, and establishes the principles which will henceforth guide geologists in the study of the massive crystalline rocks.

From the remotest times there have existed on the surface of the globe volcanoes essentially similar to those now active. Such is the doctrine which Sir Archibald Geikie maintains. He has proved the uniformity of the phenomena and of the volcanic products throughout the geological past. He has indicated the cycles of differentiation among the magmas, and their recurrence in successive ages. He has shown how the sequence and structure of ancient eruptive rocks are to be determined.

The geological historian who shall hereafter record the stages in the progress of our knowledge regarding what may be termed fossil volcanoes, will attribute their first discovery to Guettard and Desmarest; their analysis to Sorby, to the German petrographers, and to Fouqué and Michel Lévy (to whom the present work is dedicated); and their synthesis to Sir Archibald Geikie, who has resuscitated and reconstructed the old dismantled volcanoes, buried under the geological formations of Great Britain.

The author, in a preface dealing with the history of discovery in the domain of volcanic geology, introduces his subject in the following sentences.

"In no department of science is the slow and chequered progress of investigation more conspicuous than in that branch of geology which treats of volcanoes. Although, from the earliest dawn of history, men had been familiar with the stupendous events of volcanic eruptions, they were singularly slow in recognising these phenomena as definite and important parts of the natural history of the earth. Even within the present century, the dominant geological school in Europe taught that volcanoes were mere accidents. A juster appreciation of the nature of the earth's interior was needed, before men could recognise that volcanic action had once been vigorous and prolonged in many countries, where no remains of volcanoes can now be seen."

"To France, belongs the merit of having laid the foundations of the systematic study of ancient volcanoes. As far back as the year 1752, Guettard recognised that the Puys of Auvergne were volcanic cones that had poured forth streams of lava. But it was reserved to Desmarest twelve years later to examine the question in detail, and to establish the investigation of former volcanic action upon a broad and firm basis of careful observation and sagacious inference. He discovered that the volcanoes of Central France were not all of one age, but had made their appearance in a long series, whereof the individual members became less perfect and distinct in proportion to their antiquity." "While these fruitful researches were in progress in France, others of hardly less moment were advancing in Scotland. Hutton, as a part of his immortal 'Theory of the Earth,' had conceived the idea that much molten material had been injected from below into the terrestrial crust, and he had found many proofs of such intrusion among the rocks of his native country. His observations, confirmed and extended by Playfair and Hall, and subsequently by Macculloch, opened up the investigation of the subterranean phases of ancient volcanic action" (Preface, pp. vii.-viii.).

From the peculiarly favourable structure of the country, Britain has been enabled to make many important contributions to the investigation of the subject. De la Beche, Murchison and Sedgwick led the way in recognising, even among the most ancient stratified formations of England and Wales, the records of contemporaneous volcanoes and their subterranean intrusions.

A new stage in the history of volcanic geology was entered when Sorby introduced the method of microscopic examination of rocks by means of thin slices. Petrographical investigation was thereby enabled to keep pace with stratigraphical research. The rocks of the whole globe have been made to pass through the German laboratories, and thus precise knowledge has been obtained regarding the mineralogical composition and structure of the rocks, and light has been thrown on the true principles of their classification. In France, Fouqué and Michel Lévy, studying volcanic rocks both in the field and in thin sections, have been able to reproduce the principal types artificially in their laboratory.

In Sir Archibald Geikie's volumes the study of ancient volcanic rocks now emerges from the laboratory, and is prosecuted under the broad sky among the crags, the shores, and the isles. Not that the minute description of internal structure or of chemical and mineralogical composition is neglected by him; but the rocks are no longer looked at as they are in themselves: their chief value is now sought in their association as parts of a connected volcanic history. A dyke is only noticed when its description allows it to be connected on the one side with a subterranean reservoir, and on the other with its superficial display of lavas or fragmental discharges. The rocks are studied as much from the point of view of their origin as from that of their composition, and their structure is shown to be in relation to some determinate part of a volcanic group. All that has been done, all that has been said in regard to these questions, will be found summed up in Sir Archibald's work, while his masterly exposition of the history of volcanoes from the earliest times down to our own day is enhanced with ingenious conclusions respecting the nature and causes of volcanic action.

The fossil volcanoes reveal no craters. No trace of their original cones has survived to our time, save in some exceptional cases where they have been entombed under lavas, or have been preserved under other accumulations. These and other characteristics constitute difficulties in the study of ancient volcanic action. But they have not proved insuperable. Such has been the progress of this study, that it has already thrown light on the structure and mechanism of the active volcanoes of the present day. Thus a comparison of the past with the present may enable us to arrive at some adequate conception of the nature and history of volcanoes in the geological history of the globe.

"In this research," as Sir Archibald Geikie remarks, "it is obvious that the presently active volcano must be the basis and starting point of inquiry. At that channel of communication between the unknown inside and the familiar outside of our globe, we can watch what takes place in times of quiescence or of activity. We can there study each successive phase of an eruption, measure temperatures, photograph passing phenomena, collect gases and vapours, register the fall of ashes or the flow of lavas, and gather a vast body of facts regarding the materials that are ejected from the interior, and the manner of their emission.

"Indispensable as this information is for the comprehension of volcanic action, it obviously affords after all but a superficial glimpse of that action. We cannot see beyond the bottom of the crater. We cannot tell anything about the subterranean ducts, or how the molten and fragmental materials behave in them. All the underground mechanism of volcanoes is necessarily hidden from our eyes. But much of this concealed structure has been revealed in the case of ancient volcanic masses, which have been buried and afterwards upraised and laid bare by denudation.

"In yet another important aspect modern volcanoes do not permit us to obtain full knowledge of the subject. The terrestrial vents, from which we derive our information, by no means represent all the existing points of direct connection between the interior and the exterior of the planet. We know that some volcanic eruptions occur under the sea, and doubtless vast numbers more take place there of which we know nothing. But the conditions under which these submarine discharges are effected, the behaviour of the outflowing lava under a body of oceanic water, and the part played by fragmentary materials in the explosions, can only be surmised. Now and then a submarine volcano pushes its summit above the sea-level, and allows its operations to be seen, but in so doing it becomes practically a terrestrial volcano, and the peculiar submarine phenomena are still effectually concealed from observation.

"The volcanic records of former geological periods, however, are in large measure those of eruptions under the sea. In studying them we are permitted, as it were, to explore the sea-bottom. We can trace how sheets of coral and groves of crinoids were buried under showers of ashes and stones, and how the ooze and silt of the sea-floor were overspread with streams of lava. We are thus, in some degree, enabled to realise what must now happen over many parts of the bed of the existing ocean.

"The geologist who undertakes an investigation into the history of volcanic action within the area of the British Isles during past time, with a view to the better comprehension of this department of terrestrial physics, finds himself in a situation of peculiar advantage. Probably no region on the face of the globe is better fitted than these islands to furnish a large and varied body of evidence regarding the progress of volcanic energy in former ages" (vol. i. pp. 5–6).

Towards the close of his second volume, after adducing in full detail the volcanic records of his native country, the author remarks that

"A review of the geological history of Britain cannot but impress the geologist with a conviction of the essential uniformity of volcanism in its manifestations since the early beginnings of geological time. The composition and structure of the materials erupted from the interior have remained with but little change. The manner in which these materials have been discharged has likewise persisted from the remotest periods. The three modern types of Vesuvian cones, Puys and fissure-eruptions, can be seen to have played their parts in the past as they do to-day."

After an introductory series of chapters dealing with general principles of investigation and interpretation, the work enters upon a detailed description of the volcanic phenomena of the successive geological periods, beginning with the most ancient.

"Among the earliest igneous masses of which the relative geological date can be fixed are the dykes which form so striking a system among the Archæan rocks of the north-west of Scotland, and show how far back the modern type of volcanic fissures and dykes can be traced. No relic, indeed, has survived of any lavas that may have flowed out from these ancient fissures, but so far as regards underground structure, the type is essentially the same as that of the Tertiary and modern Icelandic lava-fields" (vol. ii. pp. 470–471).

The early Palæozoic volcanoes formed cones of lava and tuff comparable to those of such vents as Vesuvius and Etna. As illustrations of the Vesuvian type in the volcanic history of Britain, the author refers to the great Lower Silurian Volcanoes of Cader Idris, Arenig, Snowdon and the Lake District, and to the Old Red Sandstone volcanoes of Central Scotland. In the Lake District the pile of material ejected during Lower Silurian time was at least 8000 or 9000 feet thick. In the Old Red Sandstone basins of Central Scotland there were more than one mass of lavas and tuffs thicker than those of Vesuvius.

The Carboniferous volcanoes were not only abundant and persistent in Scotland, but they attained there a variety and development which give their remains an altogether exceptional interest in the study of volcanic geology. They are referable, from their characters and their age, to two different types, *Plateaux* and *Puys* (vol. i. p. 364).

In the *Plateau-type*, the volcanic materials were discharged over wide tracts of country, so that they now form broad tablelands or ranges of hills, reaching sometimes an extent of many hundreds of square miles and a thickness of more than 1000 feet. Plateaux of this character occur within the British area only in Scotland where they are the predominant phase of volcanic intercalations in the Carboniferous system, and are eminently characteristic of the earliest portion of that period. This *Plateau* or *Fissure-type* is, among modern volcanoes, best developed in Iceland. In that island, during a volcanic eruption, the ground is rent open by long parallel fissures, only a few feet or yards in width, but traceable sometimes for many miles, and descending to an unknown depth into the interior. From these fissures lava issues—in some cases flowing out tranquilly in broad streams from either side, in other cases issuing with the discharge of slags and blocks of lava which are piled up into small cones set closely together along the line of the rent. By successive discharges of lava from fissures, or from vents opening on lines of fissure, wide plains may be covered with a floor of rock made up of horizontal beds.

The author shows that, after the beginning of the Carboniferous Limestone period, when eruptions of the plateau-type had generally ceased, volcanic activity showed itself over the area of the British Isles in a different guise, both as regards the nature of its products and the manner and scale of their discharge (vol. i. p. 414). Instead of widely extended lava-sheets and tuffs, piled above each other sometimes to a thickness of many hundred feet, and stretching over hundreds of square miles, another phase of volcanism presented itself, where scattered groups and rows of *Puys*, or small volcanic cones, threw out, in most instances, merely tuffs, and these often only in trifling quantity, though here and there their vents also poured forth lavas, and gradually piled up volcanic ridges which, in a few cases, almost rivalled some of the plateaux. The evidence for these less vigorous manifestations of volcanic activity is furnished (1) by layers of tuff and sheets of basaltic-lavas intercalated among the strata that were being deposited at the time of the eruptions ; (2) by necks of tuff, agglomerate, or different lava-form rocks that mark the positions of the orifices of discharge ; and (3) by sills, bosses, and dykes that indicate the subterranean efforts of the volcanoes. The comparatively small thickness of the accumulations usually formed by these vents, heir extremely local character, the numerous distinct horizons on which they appear, and the intimate way in which they mingle and alternate with the ordinary Carboniferous strata, are features which at once arrest the attention of the geologist, presenting, as they do, so striking a contrast to those of the plateaux.

In a vast number of ancient volcanic vents, no trace can be discovered of their connection with any fissure in the earth's crust (vol. i. p. 53). Such fissures may, indeed, exist underneath, and may have served as passages for the ascent of lava to within a greater or less distance from the surface. But it is established in these volumes that volcanic energy has the power of blowing out an opening for itself through the upper part of the crust without the existence of any visible fissure there. What may be the limits of depth at which this mode of communication with the outer air is possible we do not yet know. They must obviously vary greatly according to the structure of the terrestrial crust on the one hand, and the amount and persistence of volcanic energy on the other. But where the thickness of rock above the end of the fissure is not too great, the expansive energy of the vapours absorbed in the magma may overcome the resistance of that cover, and blow out an orifice by which the volcanic materials can reach the surface. In an ordinary volcanic orifice the ground-plan of the neck is usually irregularly circular or elliptical.

The discharge of explosive vapours was sometimes the first and only effort of volcanic energy. Generally, however, fragmentary volcanic materials were ejected, and cones of tuff were formed ; or, if the eruption was more vigorous, lava was poured out. Towards the close of a volcanic period, the vents were gradually choked up with the fragmentary materials that were ejected from, and fell back into them. When the vents were plugged up by the consolidation of fragmentary matter, or the uprise of lava in them, the final efforts of the volcanoes led to the intrusion of *sills* and *dykes*, not only into the rocks beneath the volcanic sheets, but also, in many instances, into at least the older parts of these sheets themselves. The size and extent of the *sills* may thus be a record of the intensity of this latest phase of the volcanic eruptions.

The chief products of the Carboniferous volcanoes are basic rocks, dolerites, and basalts, with andesites ; they are somewhat more acid in the necks, where are found diabases, trachytes, and phonolites. The Puy lavas are generally more basic than the lavas of the plateaux.

The Permian volcanoes were the last of the long Palæozoic series, and, so far as we yet know, the whole of the Mesozoic periods, within the area of Britain, were absolutely unbroken by a single volcanic eruption. It was an era of geological calm, during which the Triassic, Jurassic and Cretaceous formations were slowly accumulated over the larger part of Europe. The stratigraphical quietude was not, indeed, unbroken. The widespread subsidence of the sea-bottom was interrupted here and there by important upheavals, and considerable geographical changes were in process of time accomplished. But, save in one or two widely separated areas of Europe, there were no active volcanoes over the whole continent.

After the enormous interval represented by the whole of the Mesozoic and the earlier part of the Tertiary formations, a time of disturbance arose once more, and a surface of 40,000 square miles was covered in the north-west of Britain by great basalt-floods. The whole of these latest volcanic manifestations were comprised within the earlier (Oligocene and, perhaps, early Miocene) part of older Tertiary time.

The first indications of Tertiary volcanic energy in the north-west of Europe were displayed in the formation of numerous parallel fissures extending in the British Isles in a general north-westerly direction. Between the walls of these opened fissures a basic magma rose and solidified, thus constituting the innumerable dykes of the region. Sometimes the magma reached the surface of the ground, and streaming forth there formed the successive sheets of basalt in the great plateaux. In some instances, as in modern Icelandic eruptions, the lava may have issued immediately from the fissures ; in others its rise has been accompanied with the formation of small cones along the line of a chasm. During a tolerably protracted period, basic and intermediate lavas (basalts, dolerites, andesites, and trachytes) continued to be poured out, together with possibly an occasional outflow of rhyolite. These eruptions took place from many points, and not from great central volcanoes like Vesuvius. The result of their operations was to bury under more than 3000 feet of volcanic materials the broad valley between the mainland of Scotland and the chain of the Outer Hebrides. This long series of eruptions is shown to have been subaerial by the terrestrial relics—plants, insects, river-beds and lake-bottoms preserved under and between the lavas. Gradually, as the pile of volcanic material grew in thickness, the magma was less frequently ejected to the surface, but it insinuated itself underneath to form there sills or intrusive sheets.

The second stage in the Tertiary volcanic history is revealed by the great bodies of amorphous and banded gabbro which form so prominent a feature in the Inner Hebrides. These eruptive masses have disrupted the lavas of the plateaux which are more or less metamorphosed around them, and are traversed by a fringe of finer-grained sills and veins of dolerite, gabbro, troctolite, picrite, &c., which have often insinuated themselves between the sheets of the plateau-basalts. The coarse-grained and banded gabbros may have consolidated at some depth; at least nothing is yet certainly known of their superficial equivalents.

The third stage of activity, probably long posterior to the second, likewise furnishes no evidence of any superficial ejection. It is recorded by a series of markedly acid rocks—obsidians, felsites, rhyolites, porphyries, granophyres, and granites. These rocks form huge conical hills, which in outward aspect recall the trachytic Puys of Auvergne. They traverse alike the plateau-basalts and the bosses of gabbro, into which they send many dykes and veins. They also project numerous thick sills into the formations lying underneath. The rocks around these acid protrusions have been greatly metamorphosed, while the granophyres and granites have in turn undergone considerable change in composition from having caught up and assimilated sometimes a fourth of their bulk of basalt or gabbro.

After the uprise of the granophyres with their surrounding network of felsitic dykes and veins, a new ascent of basic material manifested itself, recalling that of the earliest basalt-dykes, but on a minor scale. The dykes then formed cut all the other members of the volcanic series, including the granophyres. No trace remains of any superficial discharges connected with these latest dykes. If they ever gave rise to outflows of lava, these have long since disappeared in the vast denudation which the Tertiary volcanic rocks have undergone.

The latest eruptions of North-Western Europe, forming the Tertiary volcanic series, are shown by Sir Archibald Geikie to have far exceeded in area, and possibly also in bulk of material discharged, all the eruptions that had preceded them in the geological record.

We learn further that neither in their forms or products, nor by their extent and vigour, did the volcanic manifestations of the successive ages of the geological past materially differ from those of the present time. There is assuredly no evidence that volcanic energy has gradually waned since the dawn of geological history.

A consideration of the distribution of the volcanic rocks in time shows not only how singularly uniform the course of volcanic activity has been, but that there is no evidence of the cessation of any of the broader petrographical types during geological history. Quite as much variety may be observed among the erupted materials of Tertiary time in Britain as among those of the early ages, when the earth was younger and its volcanic vigour might be supposed to have been greater and more varied than it is now.

From the evidence detailed in these volumes, it appears that the sequence from basic to acid discharges was on the whole characteristic of each eruptive period. It is obvious however, the author observes, that as the protrusions of successive periods took place within the same limited geographical area, the internal magma during the interval between two such periods must in some way have been renewed as regards its constitution, for when, after long quiescence, eruptions began once more, basic lavas appeared first, and were eventually followed by acid kinds.

Various opinions have been propounded as to the cause or causes of the differentiation observable in erupted masses, but none of them are entirely satisfactory. We must await the results of further exploration in the field and of continued research in the laboratory.

What appears to have taken place within a subterranean molten magma which has been propelled into the earth's crust as a boss or laccolite, with or without a connected system of dykes, may possibly be made to throw some light on the remarkable changes in the characters of lavas successively erupted from the same vent during the continuance of a volcanic cycle. Whether or not any such process of differentiation can be proved to take place within a subterranean volcanic reservoir, the sequence of erupted lavas bears a curious resemblance to the order in which the constituents of some large bosses succeed each other from margin to centre (vol. i. p. 92).

Sir Archibald Geikie has written the history of the ancient volcanoes of Britain in a series of attractive chapters, which he has illustrated with more than four hundred sketches, photographs and maps. But the fine work with which he has enriched science is much more than a detailed description of the crystalline rocks of his own country. He elucidates their structure and arrangement, and explains thereby their history. He rises from a consideration of facts to a discussion of the cause of volcanic phenomena. He makes the extinct volcanoes bear their testimony in favour of the uniformity and unity of the laws of nature. His work will remain one of the monuments of our time, establishing for the future the conception of the continuity of volcanic phenomena from the earliest periods, and, so far as the geological records go, demonstrating that the interior of our planet has reacted on its exterior in the same way and with the same results.

CHAS. BARROIS.

AMERICAN MATHEMATICS.

Higher Mathematics: a Text-book for Classical and Engineering Colleges. Edited by Mansfield Merriman and Robert S. Woodward. Pp. xi + 576. (New York: John Wiley and Sons. London: Chapman and Hall, Ltd., 1896.)

THIS is a style of mathematical treatise to which we are not accustomed in this country, from the luxury of the print and size of page, as well as for the refreshing novelty and interest of the contents.

Till recently, it was thought that the study of mathematics was not likely to flourish in America, as *trop vieux jeu* by the side of the new physical and biological sciences. To-day, however, it is the American student who is the most enthusiastic follower of recent mathematical development, while we in this country are being left far behind.

The words on the title-page—A Text-book for Classical and Engineering Colleges—the equivalent of our own—For Schools and Colleges—is not, however, taken, as with us, to be the rendering of *In usum Delphini;* all human interest arising from the application of theory has not been carefully eliminated from the pages, as